SCAN to BIM Beyond a Final BIM: Why, When and How

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SCAN to BIM Beyond a Final BIM: Why, When and How

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Abstract. Building Information Modeling (BIM) has become a must in architecture when it comes to new buildings, but in heritage buildings and in rehabilitation projects, it is still a debate if it's useful or efficient to make a BIM model. In this paper we analyze and propose When, How and Why modeling in BIM should be a standard process for rehabilitation projects in which an architectural has been performed. In the field of heritage architecture, archeology and rehabilitation, to create an as-built model to work on, it is needed an architectural survey using a laser scan or/and photogrammetry, which captures dense 3D measurements of the building, so architects can make studies of its geometry, detect pathologies and use it as a base for their new designs. However, even though the 3D surveying technics has evolved in the recent years, in the world architecture, the point clouds are still pretty unknown, therefore for many architects are useless information in that format. So, it is necessary to convert this 3D information as point clouds to a more common file like 2D vector drawings in CAD. For this process, it should be question if and how modeling in BIM from the point cloud (scan to BIM) helps to this purpose, without taking into the account that modeling in BIM you get a BIM model, which in rehabilitation and heritage is still not common enough to work with it. Analyzing the information of the point clouds, the typology of the building, the timings, the precision required, and how works a BIM software (Revit) and its libraries; we conclude that, in some particular projects, as far as technology and architecture field are nowadays, to make a useful documentation for rehabilitation modeling in BIM the building in a specific LoD directly from a point cloud (scan to BIM), it is an upgrade in the process beyond the fact of having a BIM model, that is to say, you can get the same documents, but with better quality results, in a more efficient way and less time spend. We ended up with a list of characteristics a building must have for this scan to BIM process is an efficient step and how this should be performed. This paper explores the efficiency of the Scan to BIM process for specific rehabilitation projects, testing it in two different case studies: a large scale building with repetitive elements (old military hospital in Valencia) and a small one with unique elements (classified single family house in Barcelona).

1. Introduction

The incentive of this study was born from the need of the VIMAC lab to distinguish methodologies to document and represent heritage buildings, in relation to the objectives, scopes, time limits of the projects and the representation techniques, that every project individually requires; even though all in all they define common approximation methodologies. Primarily focused in the new technological challenges that rise up with the BIM implantation in the architectural surveys with the technologies of

Terrestrial Laser Scanning (TLS) and Photogrammetry (SfM). The BIM projects from an architectural survey allow to go in depth in the documentation of heritage buildings, but some questions appear about in which cases is more feasible and how it has to be implemented considering the precision and the restrictions of every project. Moreover, there are some movements that are seeking the standardization and implementation of BIM in the Spanish region and the European Community.

This movement generate guidelines that promote the use of BIM technologies, which must be collaborative with different disciplines and work teams, making possible that all the work realized complement each other and a better understanding of the heritage goods is better understood, taking into account that the protection of it, starts with its knowledge.

In Spain, the organization that has the function of implanting the BIM is the EsBIM, a team of multidisciplinary technicians who are working on generating standards and methodologies to set it up in this state. Compared to the rest of Europe, Spain is one of the countries with less BIM guidelines or methodologies, in both public organizations and private companies. A survey done by EspcioBIM, shows that the 28% of the participants (2000 people that works in this sector) don't know BIM, a 31% slightly knows it, a 25% knows enough, and just a 16% knows it in depth. Fundamentally, the fact that there is no law that forces the use of BIM, generates that the construction sector doesn't bet on it with enough strength, among other reasons. Furthermore, there aren't many specialized people to implement BIM in the private companies, with what the dissemination of this methodology is even more obstructed. There are more organizations working on the implementation of BIM in Spain, among them, the iTEC (Institute of Construction Technology of Catalunya), which is adapting a product catalogue and virtual models to use it with BIM technologies, based in the standards protocols. Currently, private dealers are joining the initiative contributing with their products in the mentioned standards.

At the end of 2018, it was published an action plan in the whole state based in the directive 2014/24/UE (article 22), which obliges the companies that participate in public architecture competitions to use BIM. For 2020, it is expected for all the public infrastructures and equipment to be produced in BIM in all their phases: design, construction and maintenance.

Figure 1. Sant Miquel Montmagastre. Example of a 2D drawing representation: raster 2D with different information and 2D vectorial, from segmentation of a 3D mesh.

In this context, we made some research and test on how to apply in real projects the BIM techniques for the documentation of heritage buildings for rehabilitation projects, with the objective of determining if modelling in BIM was an efficient process to generate 2D vector drawings needed in this kind of projects. If so, this investigation searches to determine when, why and how this process is an advantage or not. We explain it through 3 representative case studies: The Mistala's hospital Manuela Solis Claràs in Valencia, a Catalogued house in Barcelona and the ruins of an old church in Sant Miquel de Montmagastre.

2. Antecedents

2.1. Scan to BIM

Scan to BIM is the process to make a BIM model from an architectural survey (TLS or SFM), usually identified as going from a point cloud model to a volumetric model associated to a database, which is a complete 3D model of the building that describes the state of the building at the time the survey was made. Modeling the building in BIM implies a better comprehension of the building, and the 3D model allows to redress and complete the 3D survey information.

Figure 2. Scan to BIM. From left to right: Point cloud, point cloud with a BIM model overlapped and BIM model.

Even though this process is long and implies to have a minimum comprehension of how the building works, making a BIM comes with some benefits regarding the management and maintenance of the heritage buildings and the possibility to work with others groups or the client in a cooperative way with regard to make improvements or details in the modeled elements.

Some articles bring up advantages of the Scan to BIM in architecture, regarding analysis, clash detection, integrations of datasets, integration of intangible information, interoperability, multi-disciplinary teams, design consistency, cost estimations, knowledge-enriched visualization of heritage artefacts, monitorization projects, planning and coordinating project resources, recording the model deliverables between different LoDs, as standard reference for project players planning model development and the interface between software [1] [2] [3]. In complementary disciplines, there are other advantages like emergency management, Service and business continuity, disaster recovery, piping, etc

BIM created models, starting from the knowledge of the building, have allowed to storage, within a single "virtual archive", the historical information of the components and the information necessary for its future maintenance, updatable over time [4].

2.2. BIM in heritage

HBIM is the adaptation of BIM applied to heritage buildings. The first step in HBIM is to define the most standard possible template in order to have a model that can be shared with other disciplines. Even though there are a lot of initiatives for its standardization (COTAC, LEGEND-HBIM…), in general, they adapt to the BIM characteristics. One of the biggest differences is the incorporation of phases converted in historical periods, where the actual phase is the common one for all the cases [5][6].

In architectural heritage restoration and conservation, it is not possible or optimal the parametrization of families, that is why it is important to distinguish between ordinary families and modelled families. There exist catalogues of antique elements parametrized as a base to be adapted, even so, some in most of the cases, the elements have to be modelled from scratch. This context could justify modelling in BIM heritage buildings, if all the heritage buildings are modeled in BIM, the HBIM library on antique elements would be extended and making HBIM models would become more efficient every time [7].

3. Cases Studies

We analyzed and compared the methodologies in some projects for architectural rehabilitation, from which we have chosen 3 representative case studies which can be seen when implementing the Scan to BIM methodology is really efficient, when it's at the limit, and when would make no sense.

Mistala's hospital Manuela Solis Claràs in Valencia: The main objective of this project was to create a BIM model from a point cloud which could be used a container model for a rehabilitation and to quantify elements of the building like the facade walls and windows. The interiors of the building were about to be demolished, so there was no need to be modelled. The Mistala's Hospital is a care center for chronic patients between the cities: Mistala and Quart de Poblet, 5 km far from Valencia. It is placed in an old military hospital complex, a wide building surrounded by dense gardens and quiet interior walks. The building to model was composed by 6 regular pavilions, an old church at the center and a front gate pavilion with a corridor that joined all of them.

This project was realized from a given point cloud without RGB information that covered most of the building (some pavilions had no scanned information). This point clouds were divided by zones (the 4 facades, roofs and interiors) and subsampled to 3mm. With a set of different point clouds prepared, the first step was to set a group of auxiliary regular planes to have the guidelines to model the building. With this infinite planes as guidelines we make sure that all the pavilions are aligned and all the walls regularized; drawing them in a big scale rather than looking at the point cloud too close, so the walls with imperceptible deformation are modeled straight.

While modeling the whole envelope of the buildings, the families of the important elements were created: windows, doors and railings. As it was a huge complex with repetitive elements, creating the families was really efficient and it could be done and improved at the same time that the building was modeled by someone else. The windows and doors were modeled with low detail as they were just to quantify them; but for the railings, which had a complex geometry, the element in the point cloud was isolated to be analyzed and modeled.

Finally, to create a more precise model with planar roof slopes, the roof from the point clouds were isolated and represented by their Z value. With the point cloud seen by its height value with a small range, the slopes of the planar roof could be easily modeled.

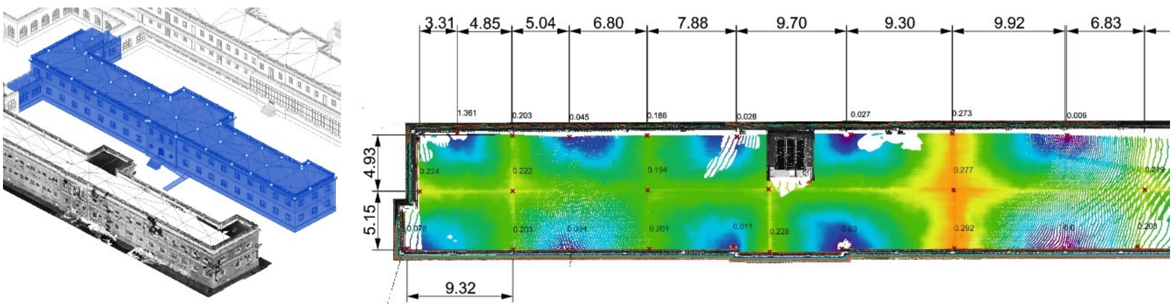

Figure 3. Roof slopes studies. Left: Scan to BIM, one pavilion with as a point cloud and one as a BIM. Right: Point cloud of the roof representing the Z values as RGB.

Since this project result was the BIM itself, some comments were written in the elements as a parameter to notify that something has been modeled interpolating information, modeled without enough information and had to be validated in-situ or if it had less level of precision than expected.

In this project with so many repetitive elements and orthogonal buildings, making a Scan to BIM was really efficient. And moreover, given the objective of the project that was to quantify the parts of the building and have an envelope to project the new parts.

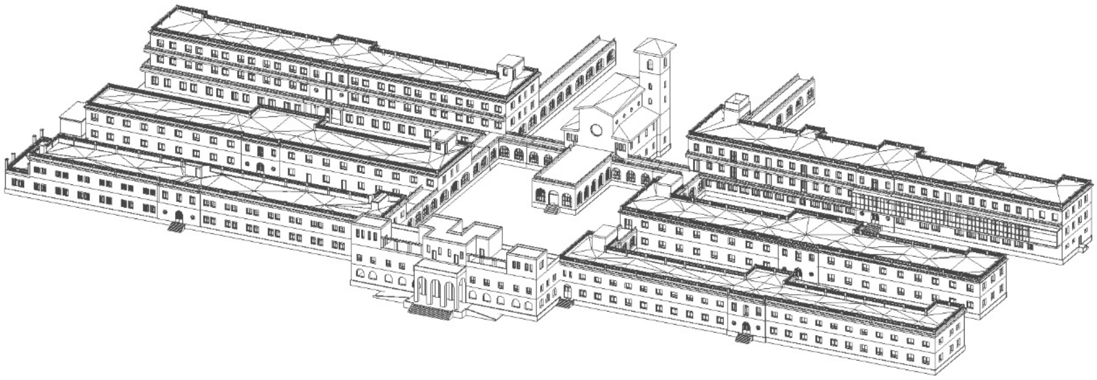

Figure 4. BIM model of the Mistala's Hospital

Catalogued house in Barcelona: The main objective of this project was to create 2D vectorial drawings (CAD) of the building, which had no information and blueprints, for a rehabilitation project.

This building is a catalogued single family house in Barcelona in the Horta neighborhood. It is a 2 floors house with an accessible roof and a garden with a pool. It has some value elements like a mosaic floor tile of huge interest.

This project was realized from scratch, making the architectural survey with scanner laser, a FARO Focus3D X330 (flight time scanner), whose capture range is 360º H * 305º V and they have a built-in 70 mega pixel camera with a High Dynamic Range (HDR) system. The survey was made with 64 positions, the minimum to have the maximum covering and to be able to align them. As the purpose of the scans is to model a BIM, the color was not important, so just 3 scans were done with HDR images, the ones in a room with a beautiful/important mosaic floor.

Figure 5. Catalogued house in Barcelona. Raster drawing of the principal façade and a section as raster and vector (CAD)

After the data taking, the RGB data was homogenized and the scans aligned and subsampled to create a good point cloud which was used to make some raster drawings and to be imported to Revit and make a basic BIM model. The BIM model was a simple one with standard families, as it was just to obtain 2D vector plans to be redrawn with AutoCAD using the rasters. The house had so many complex geometries and unique elements, that making an as built model with a lot of detail with a new specific family for each element, would have been too many time, more than drawing 2D in CAD directly from the rasters.

In this project, making the Scan to BIM process was close to be as efficient as drawing directly a 2D vector plan with CAD from the raster. It was useful since it had a really low detail and without creating families (elements were redrawn with detail in CAD afterwards). It helped to regularize the building, model the parts with no data and to generate as many drawings as needed from any level and plane.

Montmagastre Ruins church: The main objective of this project was to elaborate a good documentation of the remains of a ruined building for a student's final master final thesis. The goal of his thesis was to "define a proposal of a real Director Plan in which there is set up the needed actions to recover and give value to the architectural heritage of the Monumental Ensemble of Montmagastre" [tesis Aitor].

The Sant Miquel de Montmagastre's Church (S.XI and XVII) is a Cultural Building of National Interest which is in a bad condition and in real danger to fall apart. It is on the south slope of the Montmagastre's hill, at 745 msnm and 140m above the nearest city center. The church belongs to the Montmagastre castle ensemble (S.X) that just a few ruins remain at the top of the hill.

This project was made from scratch too, making an architectural survey with scanner laser, a FARO Focus3D X330, combined with photogrammetry. This survey was made with 52 positions, trying to have the less occlusions possible.

In this project, since the building was in ruins and had an irregular shape, it made no sense to make it with BIM. Additionally, the objective was to study the deformations and details, looking for pathologies, things that the BIM simplification can't represent or it implies too many time and plugins, that comparing it to other methodologies, made no sense to use the Scan to BIM. Therefore, this project's documentation was made with raster images and cutting a high resolution mesh.

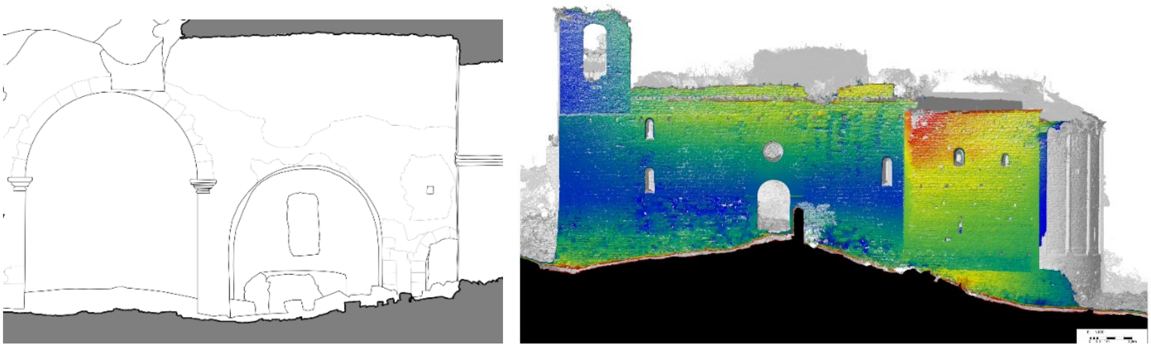

Figure 6. Montmagastre church. Left: vector drawing of the inside of the building with the section polyline got from an optimized mesh. Right: raster from the point cloud with the depth range to see the collapse of the façade.

4. Techniques of documentation of heritage plans prior to rehabilitation

For the documentation projects prior to a rehabilitation of heritage buildings are needed the exact measurements them, they are indispensable to make precis drawings for the architect to plan the rehabilitation. The TLS and SFM allows for having all this measures as a point cloud from which drawings at any plane or level can be generated.

Nevertheless, making 2D vector drawings for CAD software from a point cloud is not an automatic process. This situation involves thinking about methodologies to obtain that 2D drawings in the most efficient way, precise and coherent between them. We have tested, analyzed and compared 5 methodologies:

1. **Raster drawings:** Making 2D images of a point cloud with a point cloud software, choosing a specific scale and visible information (RGB, intensity, depth…)
2. **Tracing 2D rasters drawings with CAD:** Import raster drawings as images in XY plane in CAD and trace over them
3. **Tracing a point cloud in 3D with CAD:** import a point cloud in CAD and create planes in every section needed and crippling the point cloud, trace it in 3D.
4. **Cutting a Mesh:** Get the section lines sectioning a mesh and the projections tracing 2D rasters: Create a mesh from the point cloud and intersect it with a plane, a section polyline is obtained. Then, it is imported a raster drawing and the polyline in CAD to complete the blueprint (projections).
5. **Scan to BIM:** Modelling in BIM from a point cloud, creating all the families that are missing in the standard libraries and them exporting all the blueprints needed.

To decide which methodology is the most efficient and useful, we have compared every process evaluating time, results as precision and level of detail, and level of interpretation, regularization of elements and interpolation in missing data.

5. Efficiency of the Scan to BIM process

5.1. Efficiency evaluating time

To assess the time, it has to be evaluated how many drawings are obtained and how is the building.
On the one hand, there are methodologies which the whole process is repeated for each drawing, so the time is directly proportional to the number of plans, while in Scan to BIM and cutting a Mesh, the main time is inverted in making a 3D model, then the drawings are obtained from this model automatically. Therefore, for few plans, tracing is the better option, but if a lot of plans are needed, investing time in the 3D model is a better option.

On the other hand, geometrical complexity, the scale of the project and how many repetitive elements are there; they are factors that are important to take into account when choosing the methodology. Big Scale projects the mesh and tracing take too much time; complex geometries are better with the mesh as they are automatic, and if it has repetitive elements its better the scan to BIM as you model one family and repeat it anywhere editing few parameters.

Table 1. Methodologies' efficiency evaluating time (minutes)

Methodology	**Formula** [b]	**Catalogued house**				**Hospital**		**Montmagaste**	
		Medium complexity + Medium scale + Unique elements				*Low complexity + Big scale + repetitive elements*		*Great complexity + Medium Scale + Unique elements*	
		1 plans		*3 plans + 7 sections*		*3 plans + 7 sections*		*3 plans + 7 sections*	
Raster	*Rt*·n	Very Low	10	Very Low	100	Very Low	100	Very Low	100
Trace raster	*Rt*·n+Trs·n+Trp·n	Medium	370	High	3700	Medium	4000	High	5200
Trace P.C. [a]	Tcs·n+Tcp·n	High	452	Very High	4525	High	4450	Very High	6175
Cut Mesh	*Rt*·n+**M**+(Ms+Mc)·n+Trp·n	High	475	Medium	3130	Very High	7180	Low	3730
Scan to BIM	**BIM+Families**+BIMs·n	Very High	965	Low	1010	Low	2450	Too High	-

[a] Point Cloud
[b] n (number of drawings) // times: Rt (Raster) / Trs (Tracing raster section) / Trp (Tracing raster projection) / Tcs (Tracing point cloud section) / Tcp (Tracing point cloud projection) / M (Meshing + optimization) / Ms (Cutting the mesh) / Mc (redraw/clean Mesh section) / BIM (modelling in BIM) / BIMs (exporting BIM sections)

5.2. Efficiency evaluating the characteristics documentation

To assess quality, it has to be evaluated the advantages and disadvantages of every process of documentation in relation to the final quality and the simplification of the information from the TLS or the SFM in relation to the precision.

Table 2. Characteristics of documentation processes

	Level of documentation						**Simplification / precision**			
	Interpretation	*True magnitude*	*Scale*	*Metadata*	*Pathologies*	*Visualization*	*LOD*	*Edition*	*Precision*	*Overseg-mentation*
Raster	*Low*	*Low*	*Very High*	*Low*	*Very High*	*Medium*	*High*	*Low*	*High*	-
Trace raster	*Medium*	*Medium*	*Very High*	*Medium*	*High*	*Medium*	*Medium*	*High*	*Low*	*Low*
Trace P.C. [a]	*Medium*	*High*	*Low*	*Medium*	*Low*	*High*	*Medium*	*High*	*Low*	*Low*
Cut Mesh	*Low*	*Medium*	*Low*	*Medium*	*Very High*	*Very High*	*High*	*Medium*	*High*	*Very High*
ScanToBIM	*High*	*High*	*Very High*	*Very High*	*Very Low*	*Low*	*Low*	*High*	*Low*	*Very Low*

Raster. **Advantages:** It has a level of interpretation true to the reality without any interpretation, in a specific scale. The representation by depth ranges permits the detection of collapses. This documentation allows to get information directly from the original data, it keeps the scale that it is being worked on. **Restrictions:** The raster information can just be projected to a single plane for every top or section view, presenting occlusions. It has a true magnitude problem in relation to the section plane and projections. Every raster can just have RGB information that can represent different information, so it forces you to make a raster for every layer of information. These plans have the noise/occlusions characteristic of the TLS and SFM technology. The sections as lines from the point cloud need enough density to have continuity, so it has to be sectioned with a plane with a specific thickness, which implies a loss of precision.

Advantages of Tracing a Raster: It is a raster traced, so there are a few human interpretations possible and it is done at a specific predefined scale based on a raster. The pathologies or architectonic elements can be drawn. **Restrictions of Tracing a Raster:** The visualization of the raster in CAD can lead to precision errors at the pixel scale of the image. Every blueprint it's made from scratch, even though the image is from a same model, it is never traced at the same precis coordinates, therefore, auxiliary guidelines need to be drawn, which makes the process slower. The interpretation when drawing, it is made in 2D even having a 3D base. The lack of information of the point cloud where it is being sectioned, implies to check the complete model in another program for a proper interpretation. These interpretations imply that the model has less accuracy compared to the real building.

Restrictions of Tracing a Point cloud: the interpretation is reduced going from 3D to 2D and vice versa, it contains different layers of information and display modes of the point cloud, which for example permit to detect deformations in the middle of ramps at the same time that the building is being vectorised. Moreover, the zones without information can be interpreted directly from the point cloud. **Restrictions of Tracing a Point cloud:** The intersection between planes in 3D gets more difficult, which implies to draw in a different plane every time, constantly changing the clipping box coordinates with variations clumsy to control, taking into account that by the quantity of measurements, it is difficult to work using the points as anchors. It requires such a level of interpretation that takes time and decrease the accuracy.

Advantages of cutting a mesh: all the polylines are made from cutting the same 3D model. It has a considerable advantage compared to other techniques when it comes to times and precision, since all the section lines are made automatically with the optimized original mesh. In some zones without information in the point cloud, making the mesh makes an interpolation in that zones with very restricted characteristics, so the polylines have no human interpretation, making all the missing parts coherent between them, so the blueprint are more accurate themselves. Finally, the detection of cracks in the building can be analysed by the curvature of the mesh. **Restrictions of cutting a mesh:** The mesh may have trouble zones where the meshing software interpolate zones that are not related. To draw the projection lines, the raster plans are needed. The vector sections from meshes may have too many vertices, requiring an optimization of the mesh before cutting it or redrawing the polylines in a more efficient way.

Figure 7. Verticality of elements. Right, arch and wall in Montmagastre, both elements have too deformation and are different in every section. Left, walls in a house that are vertical and continuous in the other dimension.

Scan to BIM. **Advantages:** Since it has human interpretation, uncontrolled errors by automatic processes are avoided and the instrumental error is optimized. If there are repetitive elements with narrowed down variations, families can be created that reduce the timings and permit to work in parallel with someone else (collaborative system); moreover, it regularizes all the constructive elements. It allows to pre-configure the clipping box and working with different ones in other viewports at the same time. All the section polylines and projections are done automatic and coherent between them, from a same 3D model. Every element can have a lot of data associated. **Restrictions:** It can over simplify the heritage goods, when it comes to regularize and orthoganolize the heritage elements of the building, being then a problem in relation to the objectives and requirements of every project. This implies that decisions have to be made in relation to regularize them with the timings of the project. Having to define the LoD before starting to work implies an effort to have into account, regarding the time and the quality of the final information. The regularization of the interpretation overlooks the deformation details and pathologies, so it can be said that the interpretation reduces the accuracy of the project. Bad decisions in the modeling process can create an over segmentation of the elements that should be avoided, therefore the modelling process must be from the general parts to the particular elements, keeping clean the axis of the project in such a way that the polyline that define a wall have no vertices in the middle of the windows in theoretical straight walls.

6. Conclusions

As it has been developed in the article, the documentation of heritage buildings through massive data survey methods and field works can be realized with different methods. How to choose them depends on the scope and the objective of every project.

Figure 8. Catalogued house in Barcelona. Diagram of the process to make 2D drawings with Scan to BIM, editing them tracing in CAD with the rasters as a base.

We can conclude that BIM permits to create a common base for the work of different disciplines, that increases the value of the information for a heritage project of protection and dissemination. Even so, two methodologies can be distinguished.

On the one hand, for the buildings that are difficult to divide and present deformations which when making the theoretical model, this one ends up being too different from the reality, making difficult to obtain an accurate documentation in a specific scale, like the Montmagastre project. In these cases, the methodology that adapts better to that needs are meshing the point cloud and optimizing it to reduce the over segmentation of the polylines that cut the mesh, complementing the documentation with raster pictures.

On the other hand, for the buildings with repetitive elements and that can be classified, the scan to BIM is an optimal technique evaluating time and resources. In this cases, the model is made directly from the point cloud in a BIM software. To complement it, the raster drawings are used to represent additional information like the classification of the historic stratigraphy of the elements or the heritage ensemble, thanks to the possibility to add different information to the raster like printing a hillshade, remaking the definition of the scale in the blueprint. In details with complex geometries, the effort to model in BIM is too high in relation to the result according to the objectives and scope of the project, for this reason is more efficient to edit the 2D exported drawings of the decorative elements keeping the relation with the BIM model.

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